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Numerical Simulation of Two-dimensional Pollutant Mixing in Rivers Using RAMS

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Abstract

The analysis of two-dimensional (2D) pollutant mixing is essential to implement the effective water quality management in natural streams. In this study, numerical simulations were performed to predict the 2D pollutant behavior, using the FEM-based river analysis software, RAMS. Pollution propagation was estimated by the 2D advection-dispersion model, CTM-2D. Velocity field was computed by the 2D shallow water model, HDM-2D. Dispersion coefficients are key input parameters in CTM-2D. To calibrate these parameters, tracer tests using Rhodamine-WT dye solution were conducted in the Sum River, Korea. The calibrated longitudinal dispersion coefficients from field studies showed values about 6 times larger than the theoretical from the Elder's equation (Fischer, 1967).

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Keywords: 2D pollutant mixing; RAMS; 2D advection-dispersion model; Tracer test; Dispersion coefficient

1. Introduction

In recent years, several pollution accidents have been reported in Korea. This instantaneous injection-typed pollution not only causes malfunctioning of the facilities but also impact on aquatic eco-system. Because many water intake facilities in Korea are located along bank of the rivers, analysis of pollutant behavior in perspective of horizontal two-dimensional (2D) pollutant mixing should be investigated to efficiently prepare countermeasure to

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the pollutant accidents. This study is aimed at performing numerical simulations of 2D pollutant transport and achieving intensive field survey to calibrate the models.

1.1. Pollutant mixing

In rivers, the channel width is generally much larger than water depth with prompt mixing in vertical direction. Therefore, the 2D approach is more effective to investigate pollutant transport with respect to instantaneous injection since lateral and longitudinal mixing are governed in natural streams (Benedini and Tsakiris, 2013).

1.2. Study site

The Sum River is a tributary of the South Han River, which is a significant drinking water source for more than 1,000 million people in Seoul, Korea. The study reach is 2.5 km long with 20 to 77 m in channel width and 0.12 to 1.13 m in water depth. Since this meandering river, which has 1.66 in sinuosity larger than 1.5, is surrounded by mountainous areas, the descent flow is developed with steep bed slope (= 0.0015).

2. Model Description

River Analysis Modeling System (RAMS) is the finite element-based model and includes the depth-averaged shallow water model, 2D Hydro Dynamic Model (HDM-2D) and the depth-average advection-dispersion model, 2D Contaminant Transport Model (CTM-2D).

2.1. HDM-2D

HDM-2D is the shallow water flow model to resolve the water depth and the spatial distribution of the velocity field. The depth-averaged continuity equation and momentum equation are governing equations of HDM-2D as shown below (Seo and Song, 2010):

$$\frac{\partial h}{\partial t} + h\nabla \cdot \underline{u} + \underline{u} \cdot (\nabla h) = 0 \tag{1}$$

$$\frac{\partial \underline{u}}{\partial t} + (\underline{u} \cdot \nabla)\underline{u} = -g\nabla(H+h) + \frac{1}{h}\nabla \cdot (h\nu\nabla\underline{u}) - \frac{gn^2}{h^{4/3}}\underline{u}\left\|\underline{u}\right\| \tag{2}$$

where t = time; $\underline{u}$ = (u_1, u_2) is depth-averaged velocity vector in x -, y -directions respectively; $\underline{u}$ = gravitational acceleration; H = bottom elevation; h = water depth; ν = kinematic viscosity; n = Manning's roughness coefficient; and $\left\|\underline{u}\right\|$ = Euclid norm of velocity.

2.2. CTM-2D

The depth-averaged advection and dispersion model, Contaminant Transport Model-2D (CTM-2D) is used to analyze 2D pollutant behavior in this study. The depth-averaged form of the 2D advection-dispersion equation for a non-conservative pollutant can be written as (Lee and Seo, 2007):

$$\frac{\partial (hC)}{\partial t} + \nabla \cdot (h\underline{u}C) - \nabla \cdot (h\mathrm{D} \cdot \nabla C) + \mathrm{R}(C,t) = 0, \quad x \in \Omega,\ t \in \left[0, T\right] \tag{3}$$

where t = depth-averaged concentration; $\mathbf{D}$ = dispersion tensor; $\mathbf{R}(C,t)$ = reaction term for a non-conservative pollutant; Ω = a bounded problem domain in the 2D space; and T = objective time defined in the problem. The dispersion tensor in this equation can be defined as (Alavian 1986):

$$D_{xx} = D_L \frac{u_1^{\ 2}}{U^2} + D_T \frac{u_2^{\ 2}}{U^2} \tag{4a}$$

$$D_{xy} = D_{yx} = (D_L - D_T) \frac{u_1 u_2}{U^2} \tag{4b}$$

$$D_{yy} = D_T \frac{u_1^{\ 2}}{U^2} + D_L \frac{u_2^{\ 2}}{U^2} \tag{4c}$$

where D_{xx} , D_{xy} , D_{yx} and D_{yy} = components of the dispersion tensor; D_L = longitudinal dispersion coefficient; D_T = transverse dispersion coefficient; and $U = \sqrt{u_1^{\ 2} + u_2^{\ 2}}$.

3. Field Survey

Performing the numerical simulations requires several sets of input and measurement data to calibrate the models. In this study, topographic data, hydraulic data (e.g. flow velocity and water depth), and concentration data in lateral direction were collected at six sections shown in Fig. 1.

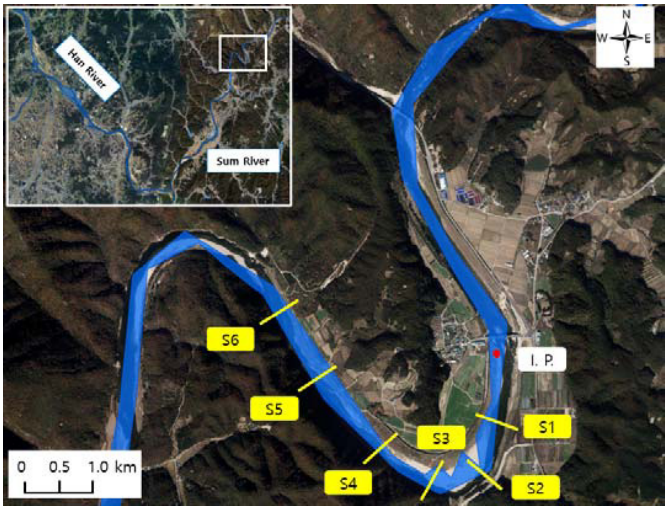

Fig. 1. Taglines for measurements in study reach of the Sum River

3.1. Hydraulic data

The measurements of depth-averaged lateral velocity and water depth were achieved, using Acoustic Doppler Current Profiler (ADCP). Based on the measured water depth, the shear velocity, U^* was estimated by the equation given as:

$$U^* = \sqrt{gHS} \tag{5}$$

where is g gravitational acceleration, H is cross-sectional average water depth and S is bed slope, respectively. The bed slope, S was calculated by Manning's equation, using the value of 0.03 as Manning's coefficient for mountain streams with gravel bed (Chow, 1959).

Table 1. Cross-sectionally averaged hydraulic data

Section	Distance from I.P. (km)	Q (m^3/s)	H (m)	W (m)	U (m/s)	U* (m/s)
I.P.	-	5.16	0.33	38	0.37	0.042
S1	0.62	5.46	0.41	24	0.91	0.099
S2	0.88	6.18	0.42	31	0.42	0.046
S3	1.22	5.88	0.54	36	0.49	0.051
S4	1.63	5.71	0.45	50	0.35	0.038
S5	2.10	4.96	0.52	57	0.37	0.039
S6	2.50	6.47	0.42	78	0.21	0.023
Average	-	5.69	0.44	45	0.45	0.050

3.2. Concentration data

The concentration of the tracer was designed to be fully mixed in vertical direction. As the tracer, Rhodamine WT solution was used because this fluorescence dye is conservative, visible, measurable at very low levels, and even toxic-free. The lateral distributions of the concentration were measured by deploying six to seven *in situ* Rhodamine WT probes (YSI 6130) with 1 s of the measurement frequency at each section. The resolution and range in measurement are 0.1 ppb and 0 to 200 ppb. The statistical values of the concentration measurement as concentration-time curve (C-T curve) were shown in Fig. 2.

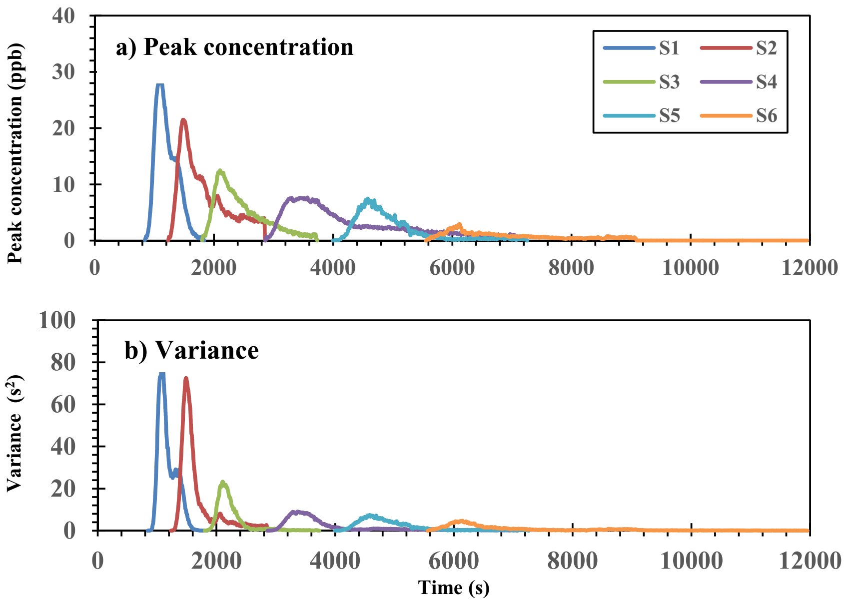

Fig. 2. Statistical information of concentration-time curve: (a) peak concentration; (b) variance

According to the statistics of the C-T curve, the peak concentration and variance in lateral direction gradually decreases as the tracers flow downstream due to lateral and longitudinal mixing. When the tracers arrived at the last section, S6, they are almost fully mixed in lateral direction.

4. Model Calibration

For the river bathymetry, the finite element mesh was generated with 3.4 x 3.4 m of structured grids, using measured bed elevation data and interpolating it with the inverse distance weighting method. In HDM-2D, upstream boundary condition, downstream boundary condition and Manning's coefficient were set up as 5.7 m^3/s, 63.2 m and 0.03, respectively. In CTM-2D, the calibrated dimensionless dispersion coefficients, related to hydraulic variables, were $D_L / HU^* = 34.31$ and $D_T / HU^* = 0.76$. The comparison between the measured and the simulated for concentration from S1 to S6 is shown in Fig. 3 as the 2D contour map of the C-T curves.

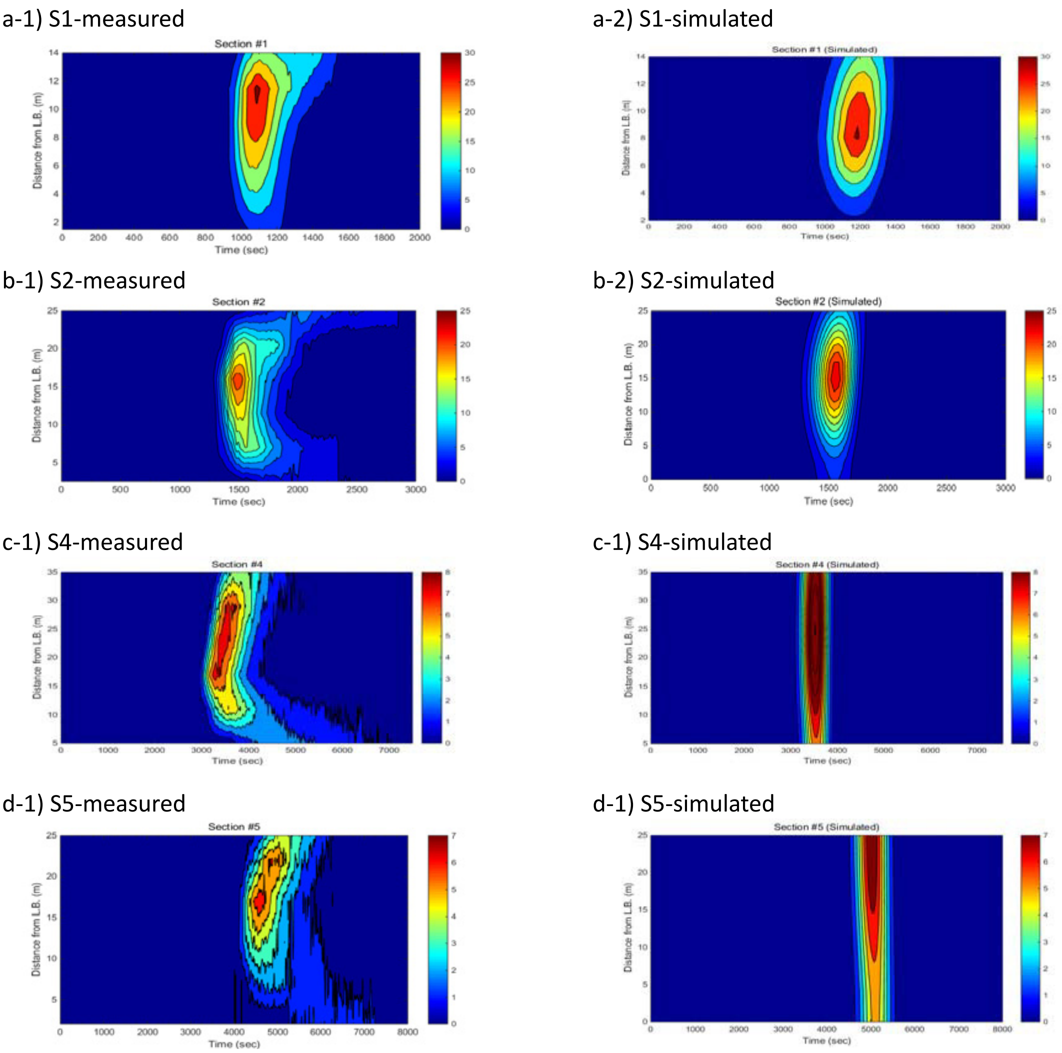

Fig. 3. Measurement-simulation comparison (x-axis = time (s); y-axis = concentration (ppb))

From the comparison between measurements and simulated concentration, the simulation well predicted the peak concentration and arrival time of centroid of the tracer cloud as shown in Table 2.

Table 2. Comparison of peak concentration between the measurement and simulation

Section	S1	S2	S3	S4	S5	S6
R^2	0.62	0.92	0.74	0.26	0.43	0.69

According to the results, the discrepancy abruptly increases after the tracer flow through S3 because the effect of recirculation and secondary current at the meandering point between S2 and S3. In Fig. 3, the long tail of the concentration at the left bank (or outer bank) was developed in the measurements due to the tracer captured in the hydraulic storage zone.

5. Summary and Conclusions

The longitudinal dispersion coefficient, D_L calibrated in this study is about 6 times larger than that from the Elder's equation, $D_L / HU^* = 5.93$ (Fischer, 1967). In the meandering channel, the recirculation zone and secondary current capture the tracers to yield the transient-storage effect in the C-T curve. Therefore, the dispersion stress in the momentum equation should be essential to efficiently investigate the 2D pollutant mixing in rivers with complex geometry and flow field.

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References

[1] Alavian, V. (1986). Dispersion tensor in rotating flows. *Journal of Hydraulic Engineering*, *112*(8), 771-777.
[2] Chow, V. T. (1959). Open channel hydraulics.
[3] Fischer, H. B. (1967). The mechanics of dispersion in natural streams. *Journal of the Hydraulics Division*, *93*(6), 187-216.
[4] Lee, M. E., & Seo, I. W. (2007). Analysis of pollutant transport in the Han River with tidal current using a 2D finite element model. *Journal of Hydro-Environment Research*, *1*(1), 30-42.
[5] Seo, I. W., & Song, C. G. (2010). Specification of wall boundary conditions and transverse velocity profile conditions in finite element modeling. *Journal of Hydrodynamics, Ser. B*, *22*(5), 633-638.